Modeling of High Column Density Systems (HCDs) in the Ly-α Forests

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Outline

1. Introduction to Lyman-α forests

2. Modeling of HCDs

3. Summary

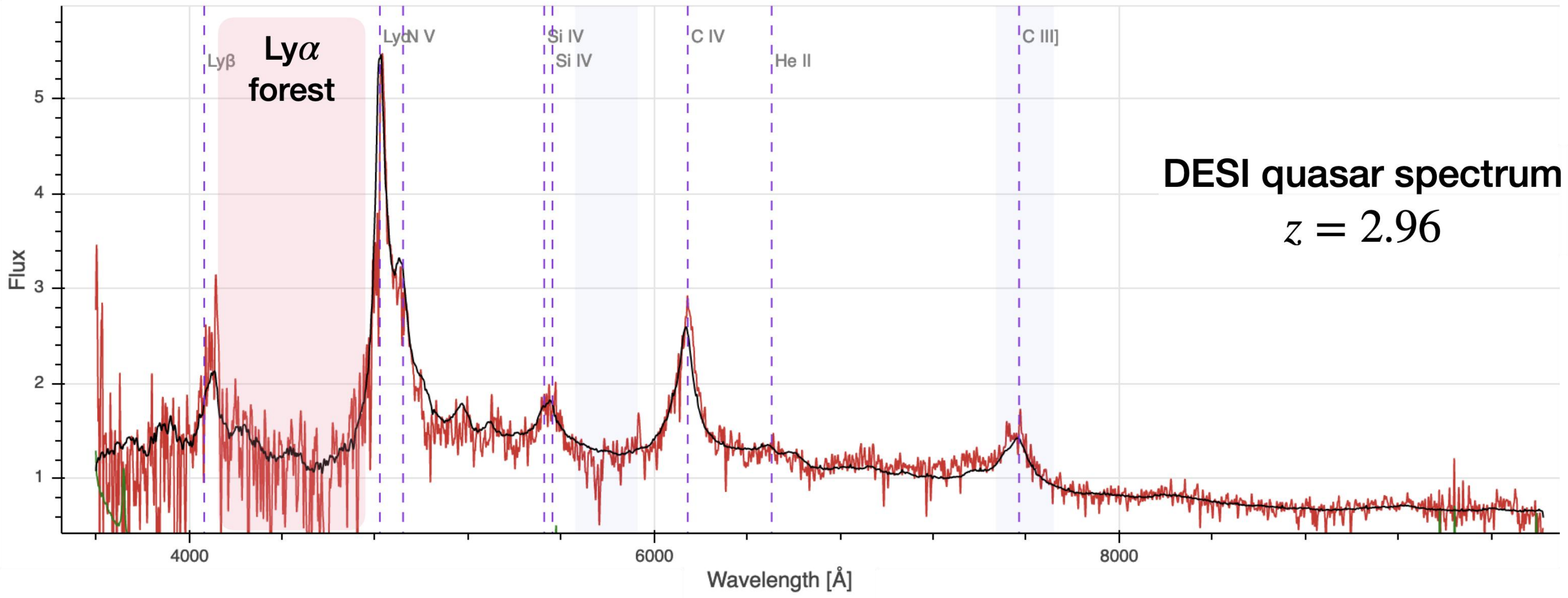
1. Introduction to Ly-α forests

Quasars

Quasars:

- The most luminous objects in the universe
- Supermassive black holes
- Accretion disks of matter

$$\lambda_{RF,\ Ly\alpha} = 1216\ \text{Å}$$

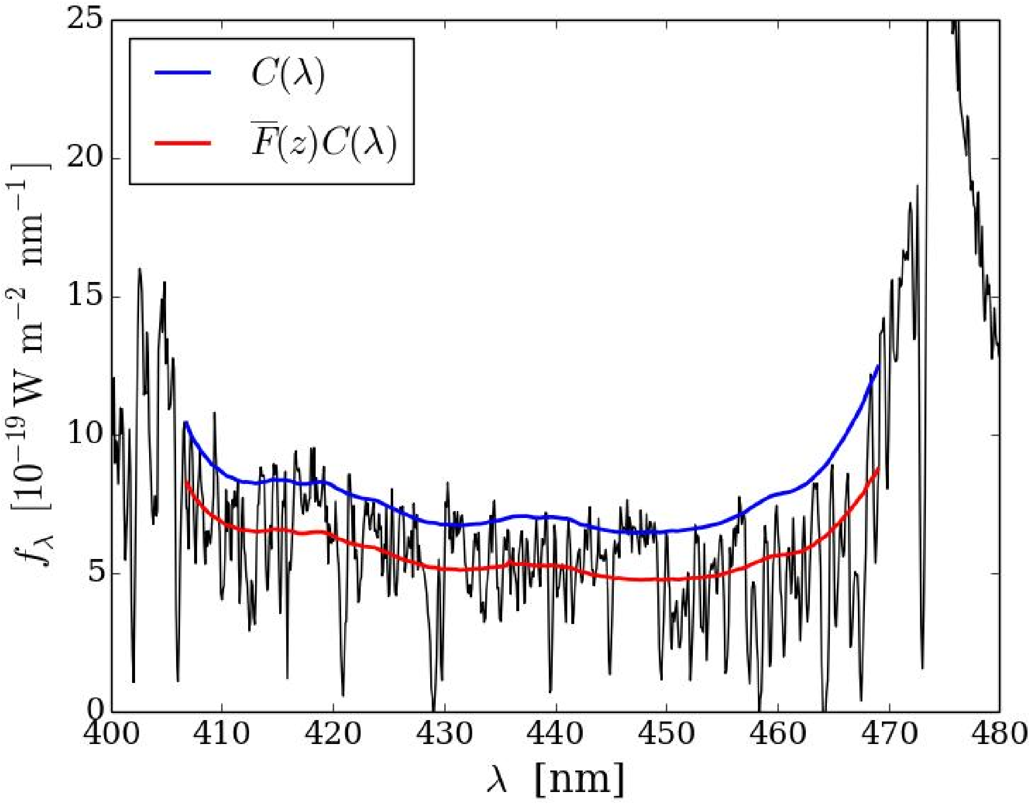


Quasar spectrum from DESI.

The Lyman-alpha forest

The Lyman-alpha forest :

- QSO continuum: unabsorbed spectrum.
- Transmitted flux field: flux/continuum.
- Trace the density fluctuations and velocity-gradient fluctuations.



Thesis: Julianna Stermer

Transmitted flux fraction:

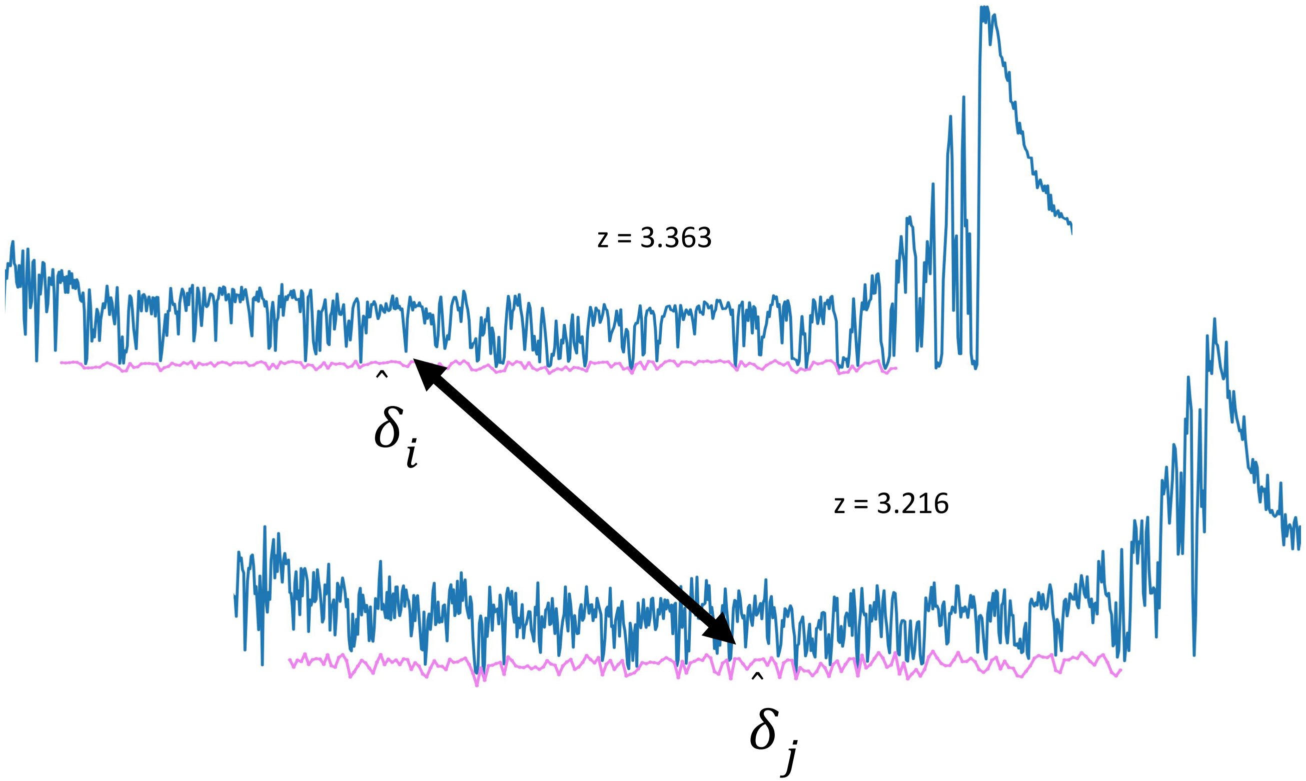
$$F_q(\lambda) = \frac{f_q(\lambda)}{C_q(\lambda)}$$

Observed flux

Quasar continuum

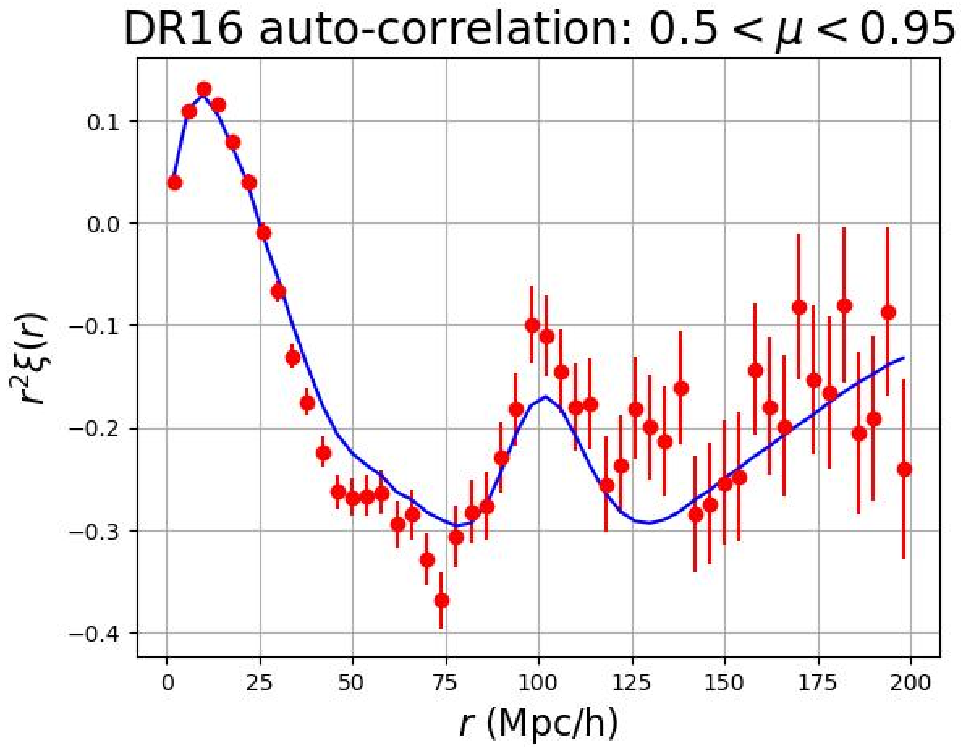
Flux delta field: $$\delta_F(\vec{x}) = \frac{F(\vec{x}) - \bar{F}}{\bar{F}} = \frac{f_q(\lambda)}{C_q(\lambda)\bar{F}} - 1$$

The Lyman-α auto-Correlation function



Thesis: Julianna Stermer

$$\xi_A = \frac{\sum_{(i,j)\in A} w_i w_j \delta_i \delta_j}{\sum_{(i,j)\in A} w_i w_j}.$$



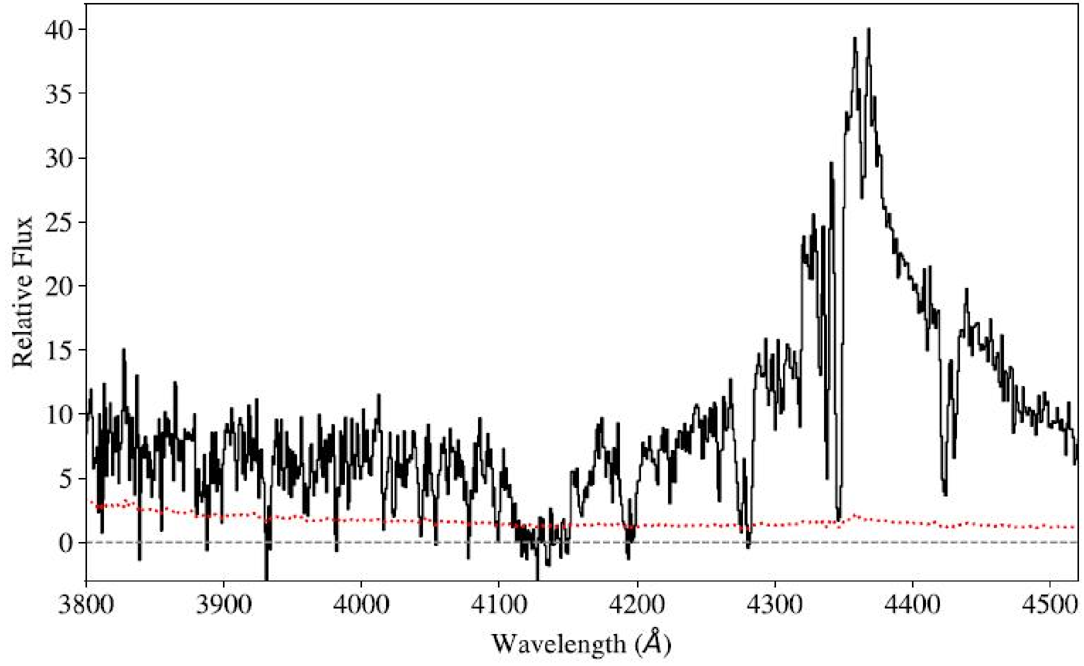
du Mas des Bourboux et al, arXiv:2007.08995

Damped Lyman-α Systems (DLAs)

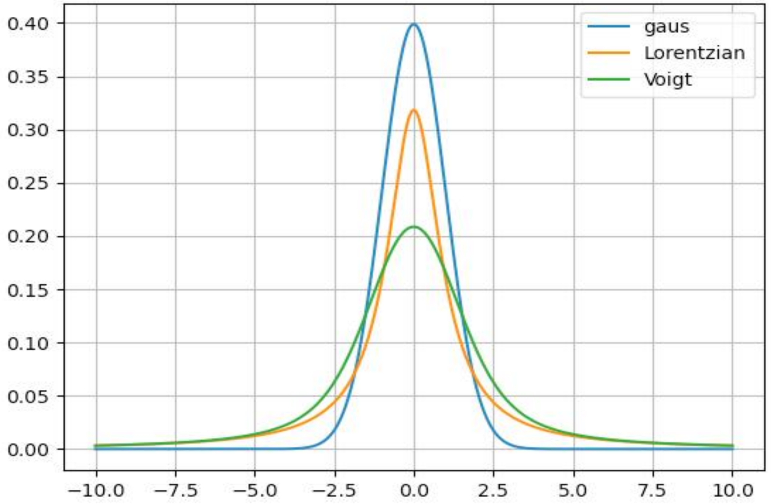
- NHI column density of a gas concentration:
  High Column Density Systems (HCDs): $N \geq 10^{17}$ / cm^2
  Damped Lyman-α Systems (DLAs): $N \geq 10^{20}$ / cm^2

- HCD absorption parametrized with Voigt profile

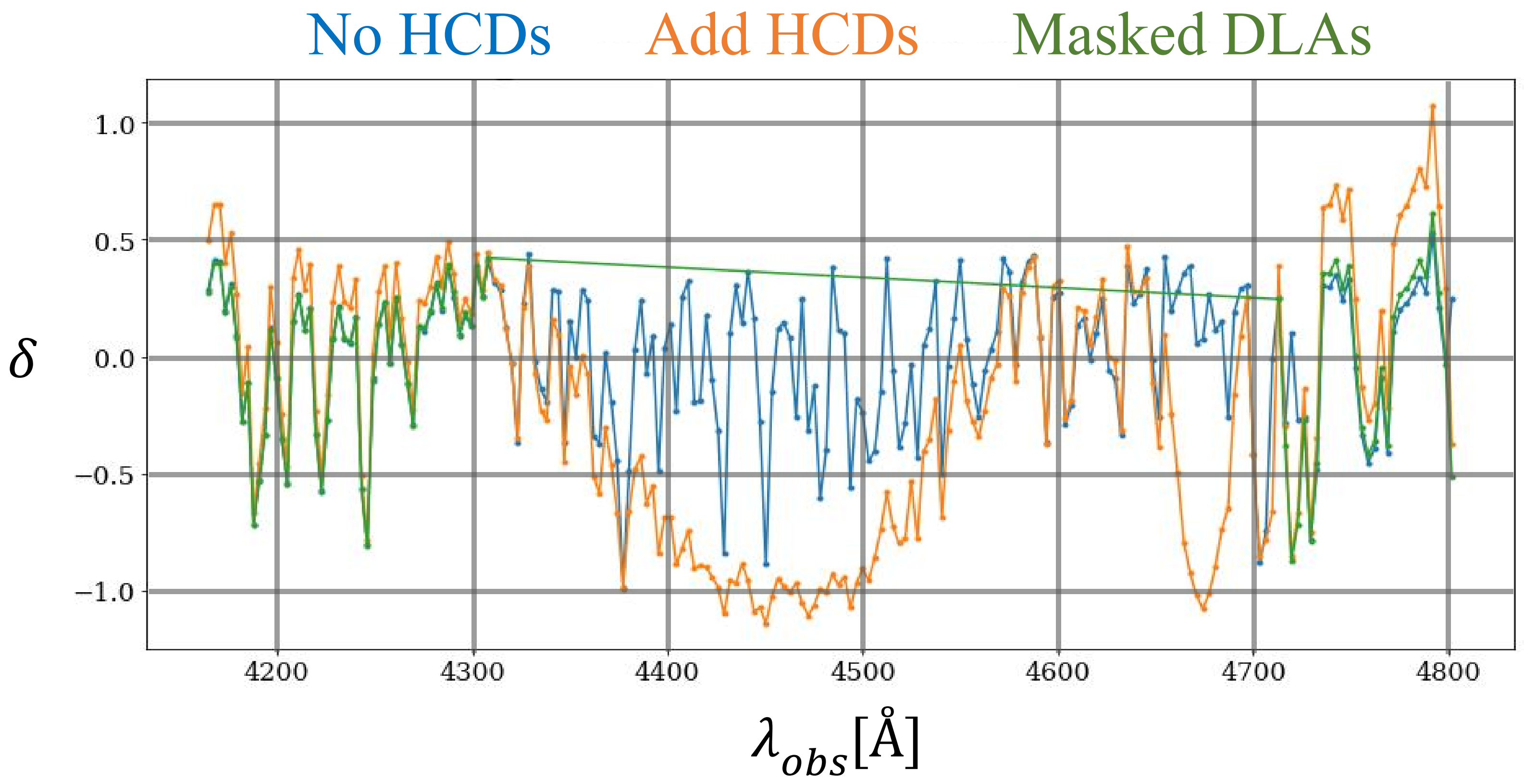
- Voigt profile = Gaussian ⊛ Lorentzian
  Gaussian: thermal Doppler broadening
  Lorentzian: cross-section



D. Parks et al. (2018)

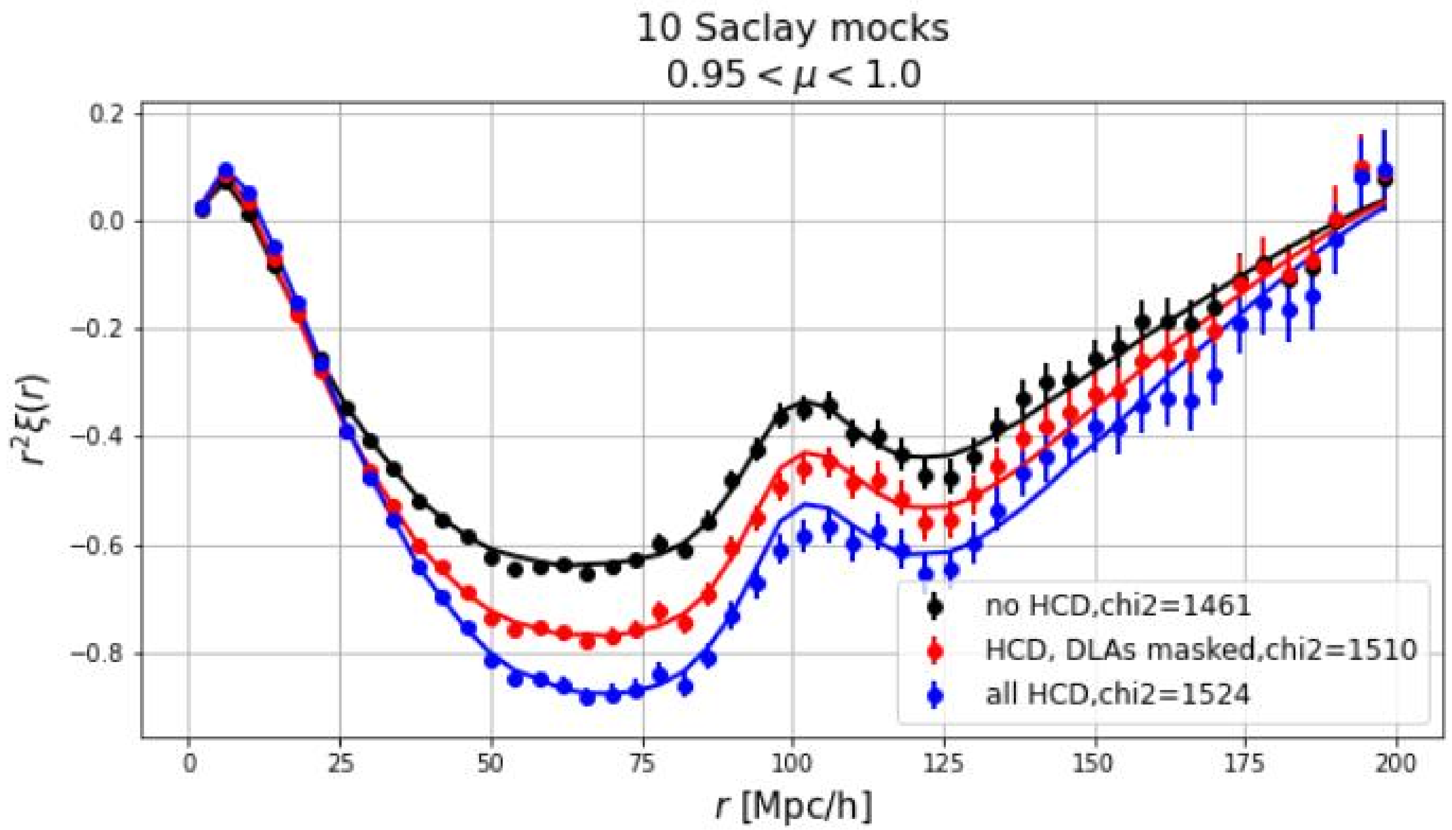


HCD effect on the correlation function



- DLAs are detectable and can be masked.
- Smaller HCDs are not detectable but they smooth the delta field (cutoff in kpar) and thus affect the correlation function.

HCD effect on the correlation function



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2. Modeling of HCDs

Model Introduction

Modeling of Ly-α power spectrum: $P_{Ly\alpha}(\mathbf{k}) = P_{QL}(\mathbf{k})D_{NL}(\mathbf{k})b^2_{Ly\alpha}(1+\beta_{Ly\alpha}\mu^2)^2$

HCD model:

$$b'_{\mathrm{Ly}\alpha} = b_{\mathrm{Ly}\alpha} + b_{\mathrm{HCD}}F_{\mathrm{HCD}}(k_{||})$$

$$b'_{\mathrm{Ly}\alpha}\beta'_{\mathrm{Ly}\alpha} = b_{\mathrm{Ly}\alpha}\beta_{\mathrm{Ly}\alpha} + b_{\mathrm{HCD}}\beta_{\mathrm{HCD}}F_{\mathrm{HCD}}(k_{||})$$

HCDs are absorbers ➡ $b_{\mathrm{HCD}}<0$ like $b_{\mathrm{LYA}}<0$

FT of HCDs profile ➡ Cut-off at high $k_{||}$

Model Introduction

Models for F_{HCD}:

$$F_{\mathtt{HCD}}^{\mathtt{Rogers}}(k_{||}) = \int (\widetilde{V-1})(k_{||}, n) f(n) dn$$

(*Rogers et al.* (2018))

$$F_{\mathtt{HCD}}^{\mathtt{exp}}(k_{||}) = \exp(-L_{\mathtt{HCD}} * k_{||})$$

- In DR16: L_{HCD}=10
- Best fit: L_{HCD}=3

$$F_{\mathtt{HCD}}^{L\beta\gamma}(k_{||}) = \frac{1}{(1 + (L_{\mathtt{HCD}} * k_{||})^{\beta})^{\gamma}}$$

Best fit: L_{HCD}=13.4

β = 153.9

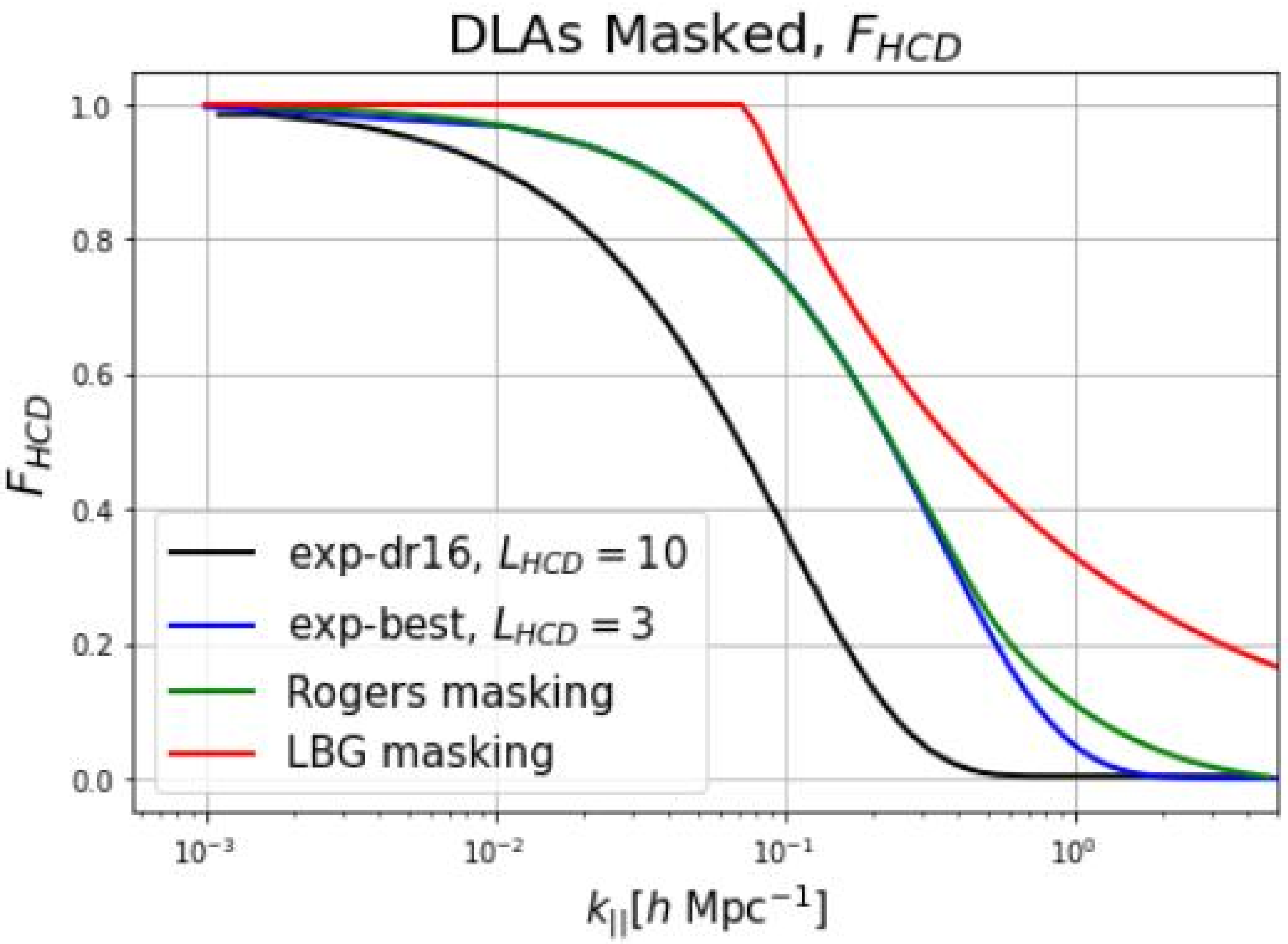
γ = 0.002776

F_{HCD} function

$L\beta\gamma$ model:

- $F_{HCD} \sim 1$ for $k_{||}<1/L_{HCD}$
  $F_{HCD} \sim (Lk_{||})^{-0.42}$ for $k_{||}>1/L_{HCD}$

- Sharp kink at $k_{||} \sim 1/L_{HCD}$



DR16, DLAs>20.3 masked

exp model:

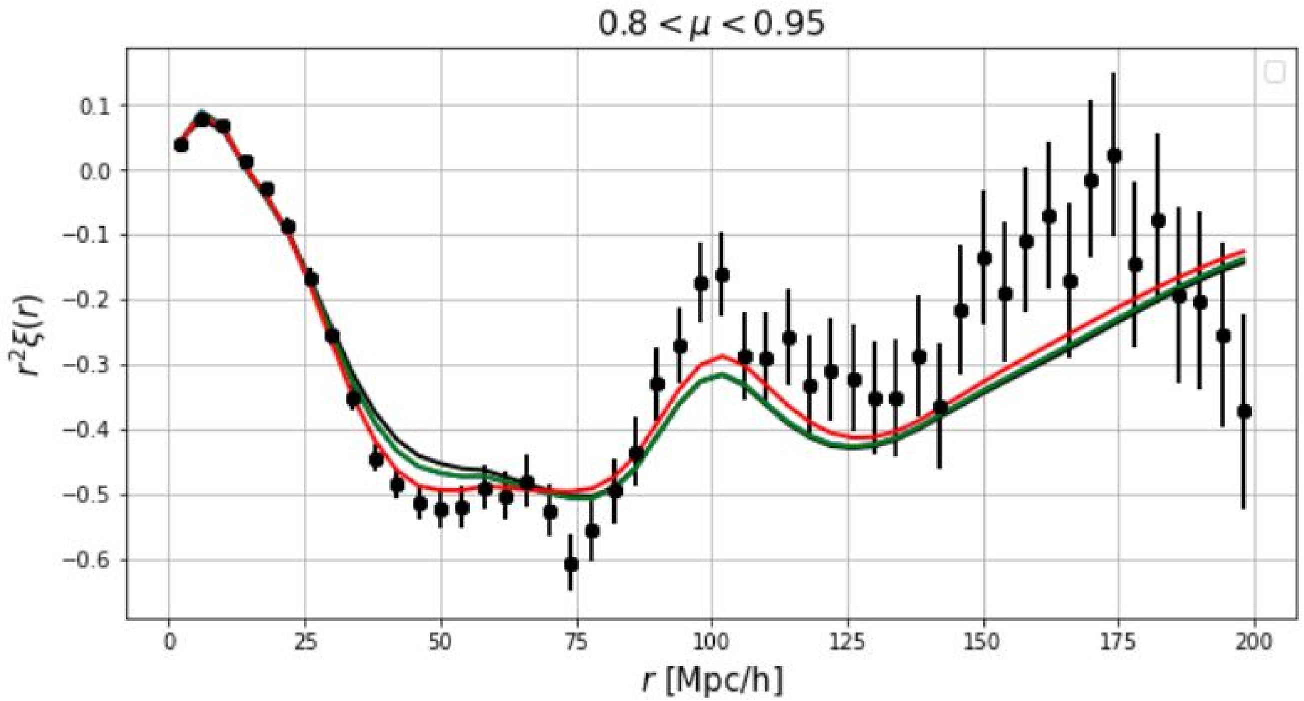
- L_{HCD}=10: χ^2=1604.73
- L_{HCD}=3: χ^2=1576.96

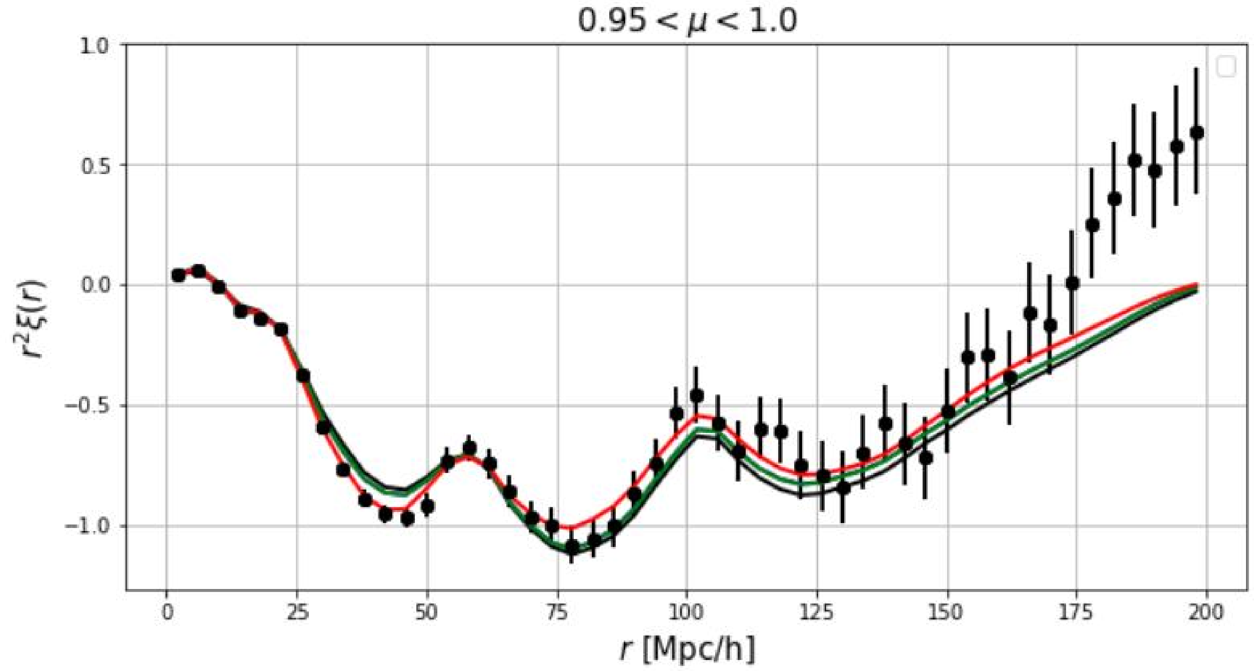
Rogers model:

- χ^2=1577.64
- Overlaps best exp model

Lβγ model:

- χ^2=1557.3
- Fit well the region 25<r<80





DLAs>20.3 masked

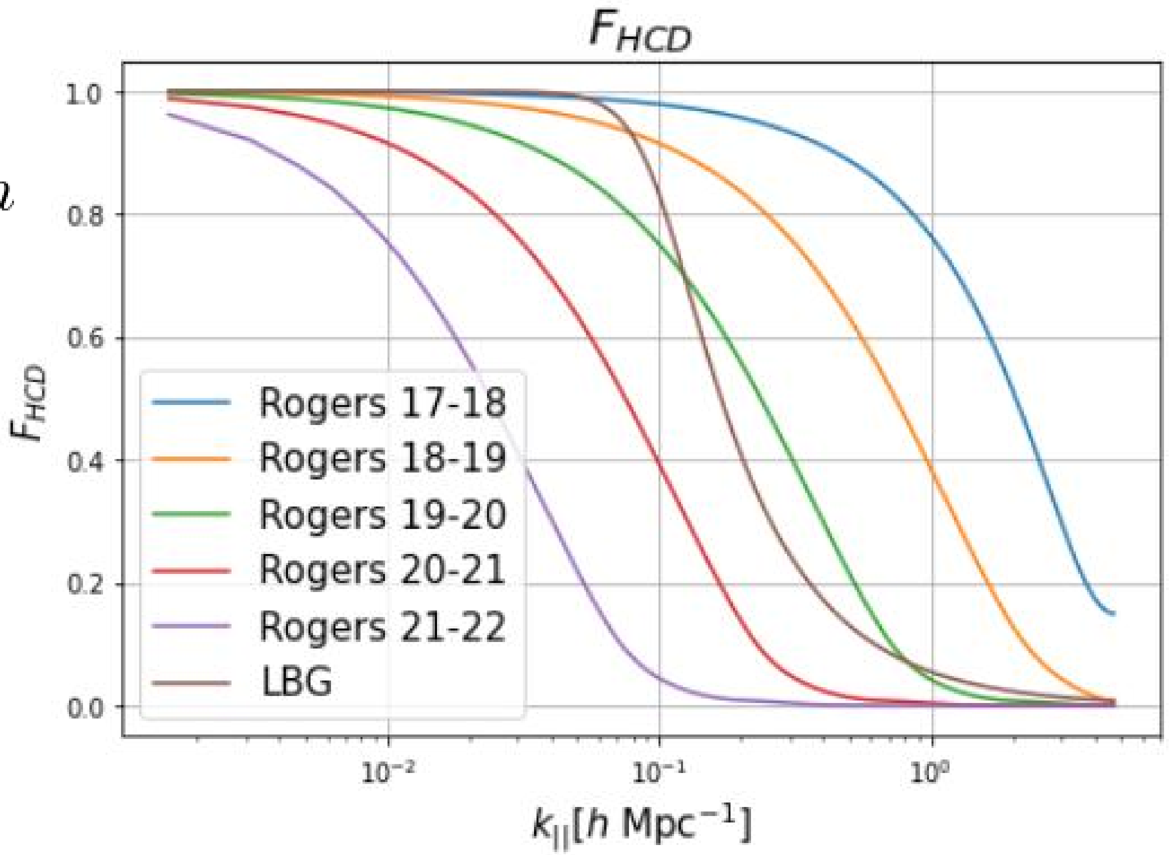
Data	Model	χ^2	β_{LYA}	β_{HCD}	b_{LYA}	b_{HCD}
DR16 data	Rogers model	1577.64	2.49±0.31	0.54±0.08	-0.074±0.018	-0.087±0.007
	Lβγ model	1557.30	2.87±0.40	0.54±0.07	-0.061±0.02	-0.088±0.009
Saclay mocks	Rogers model	1511.86	1.62±0.04	0.48±0.09	-0.127±0.04	-0.014±0.004
	Lβγ model	1509.48	1.54±0.03	0.49±0.08	-0.136±0.03	0.005±0.003

- Rogers model works for mocks but not for data
- b_{HCD}/b_{LYA} is ten times smaller in mocks than for data

F_{HCD} from Voigt profile and HCDs distribution f(n)

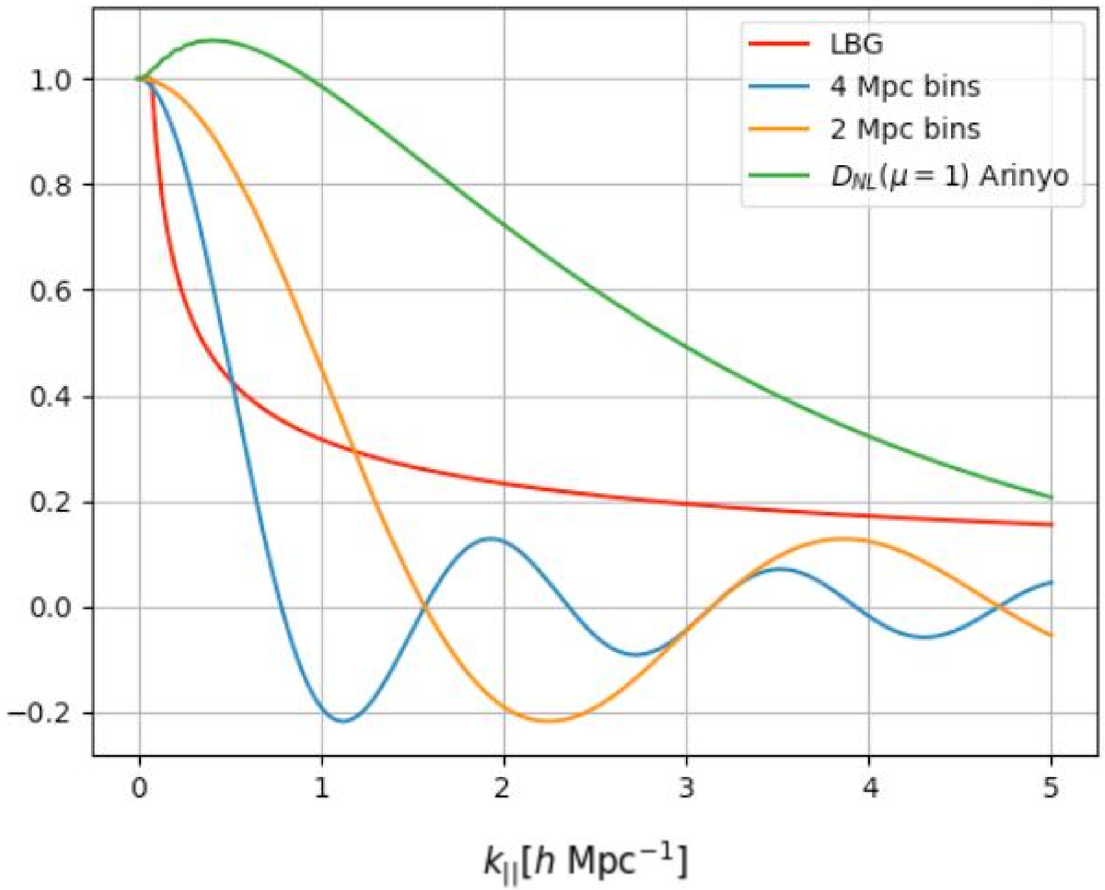
$$F_{\mathrm{HCD}}^{\mathrm{Rogers}}(k_{||}) = \int (\widetilde{V-1})(k_{||}, n) f(n) dn$$

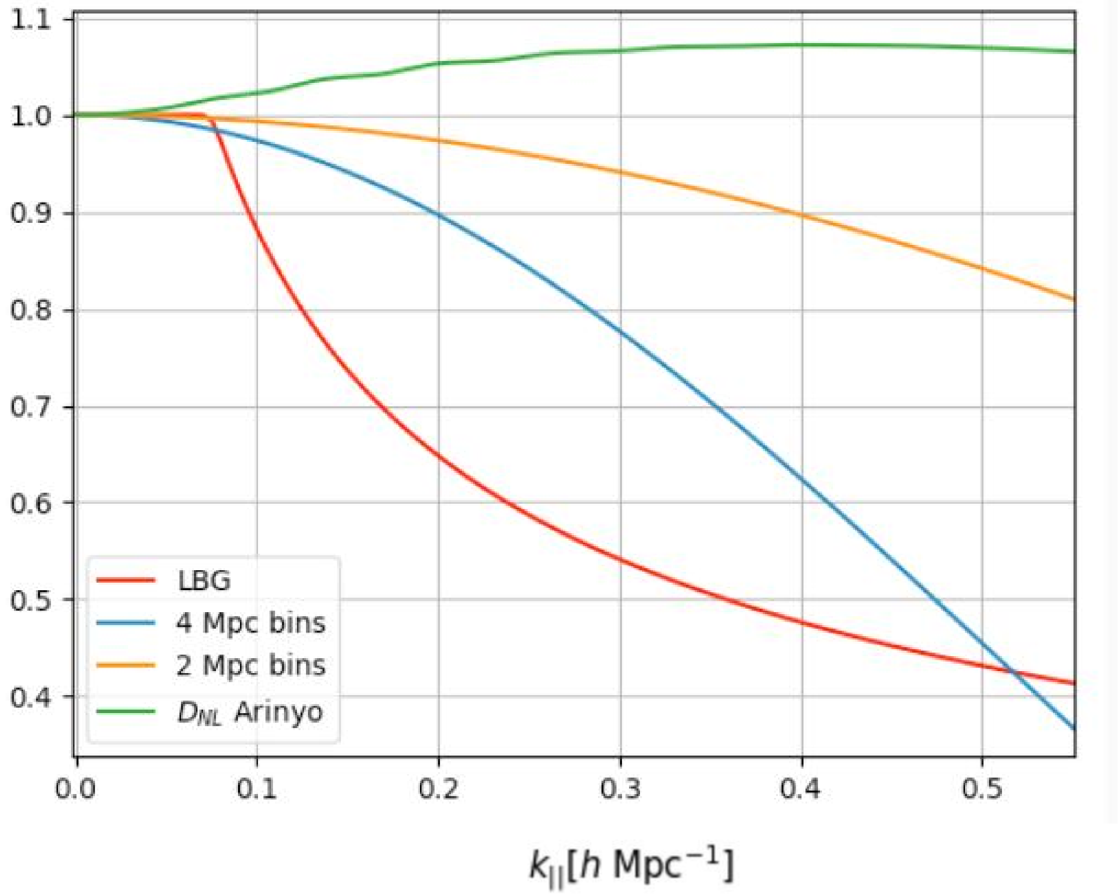
- no Voigt profile and HCDs distribution can reproduce Lβγ model.
- Lβγ model captures something other than HCDs?



Comparison of binning, D_{NL} and Lβγ scales

D_{NL}: cutoff from physical nonlinearities at small scales





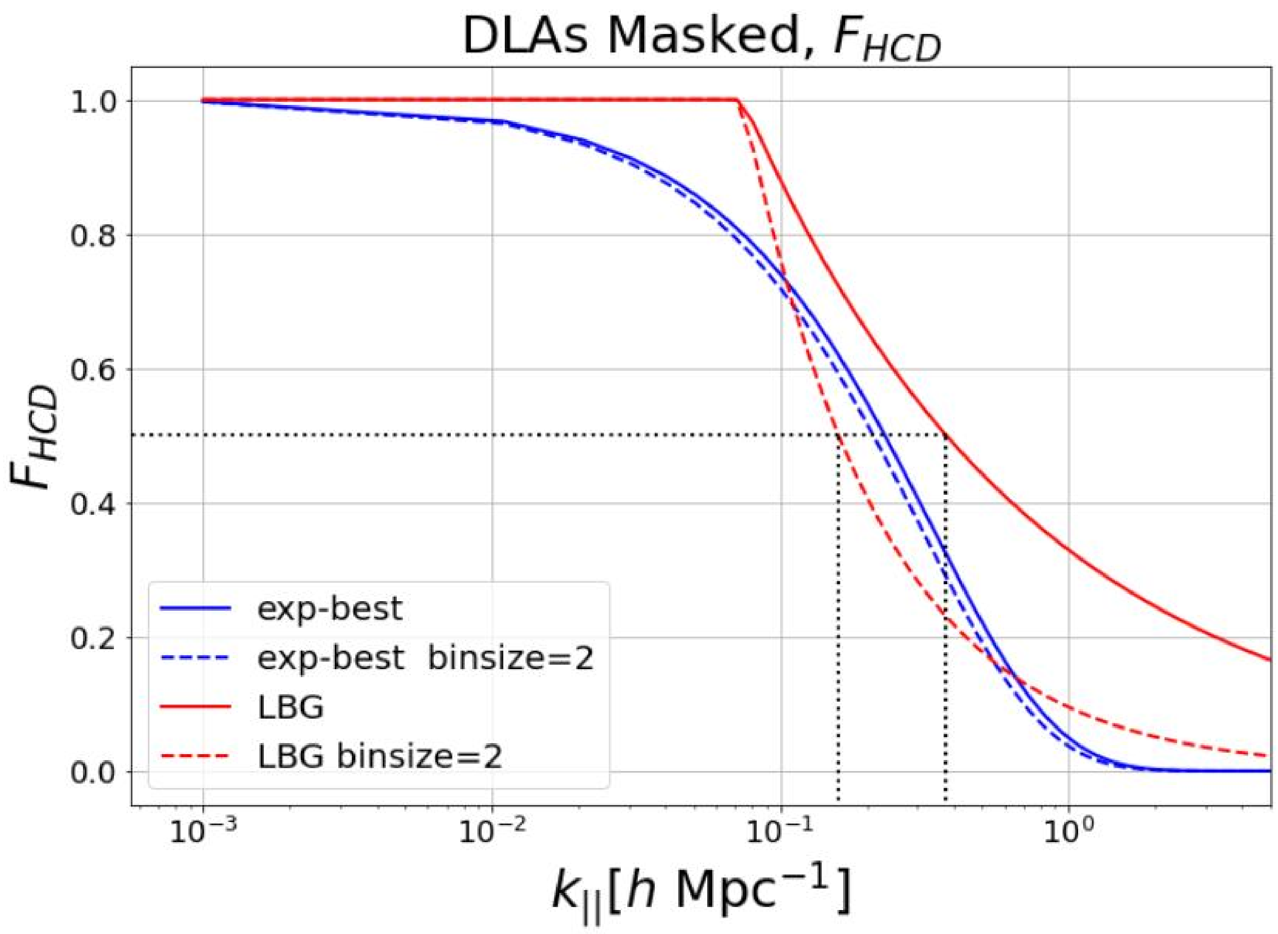
Correlation function with binsize=2 Mpc/h

exp model:

- L_{HCD}=3
- No difference for binsize=4 or 2 Mpc/h

Lβγ model:

- L_{HCD}=13.5
- the kink at $k_{||} \sim 1/L_{HCD}$, independent of binning
- $\frac{1}{2} F_{HCD}$ at $k_{||} \sim L_{bin}/L_{HCD}$, sensitive to binning



Correlation function with binsize=2 Mpc/h

Data	Model	χ^2/d.o.f	β_{LYA}	β_{HCD}	b_{LYA}	b_{HCD}
DR16 data binsize=4	exp Best	1577/1590	2.48±0.30	0.54±0.08	-0.074±0.018	-0.087±0.007
	Lβγ model	1557/1590	2.87±0.40	0.54±0.07	-0.061±0.02	-0.088±0.009
DR16 data binsize=2	exp Best	6244/6342	2.74±0.85	0.48±0.09	-0.069±0.012	-0.09±0.022
	Lβγ model	6219/6342	2.03±0.43	0.51±0.09	-0.098±0.024	-0.051±0.023

- b_{HCD}/b_{LYA} more reasonable, but still ten times larger than for mocks

Conclusion:

Modeling of HCDs:

1. Lβγ model gives smaller χ^2 (compared to voigt profile based models).

2. Lβγ model goes through the points around r = 50.

3. No combination of Voigt profiles gives the Lβγ model.

4. b_{HCD} is much larger for data than for mocks.

5. Lβγ model captures something else than HCD?

TODO:

- Physical understanding of Lβγ model
- Understand effect of binning on Lβγ model
- check whether the same problem is present in DESI data